

# Franck-Hertz Experiment

## Model SE-9639



**BroLight Technology Co., Ltd**

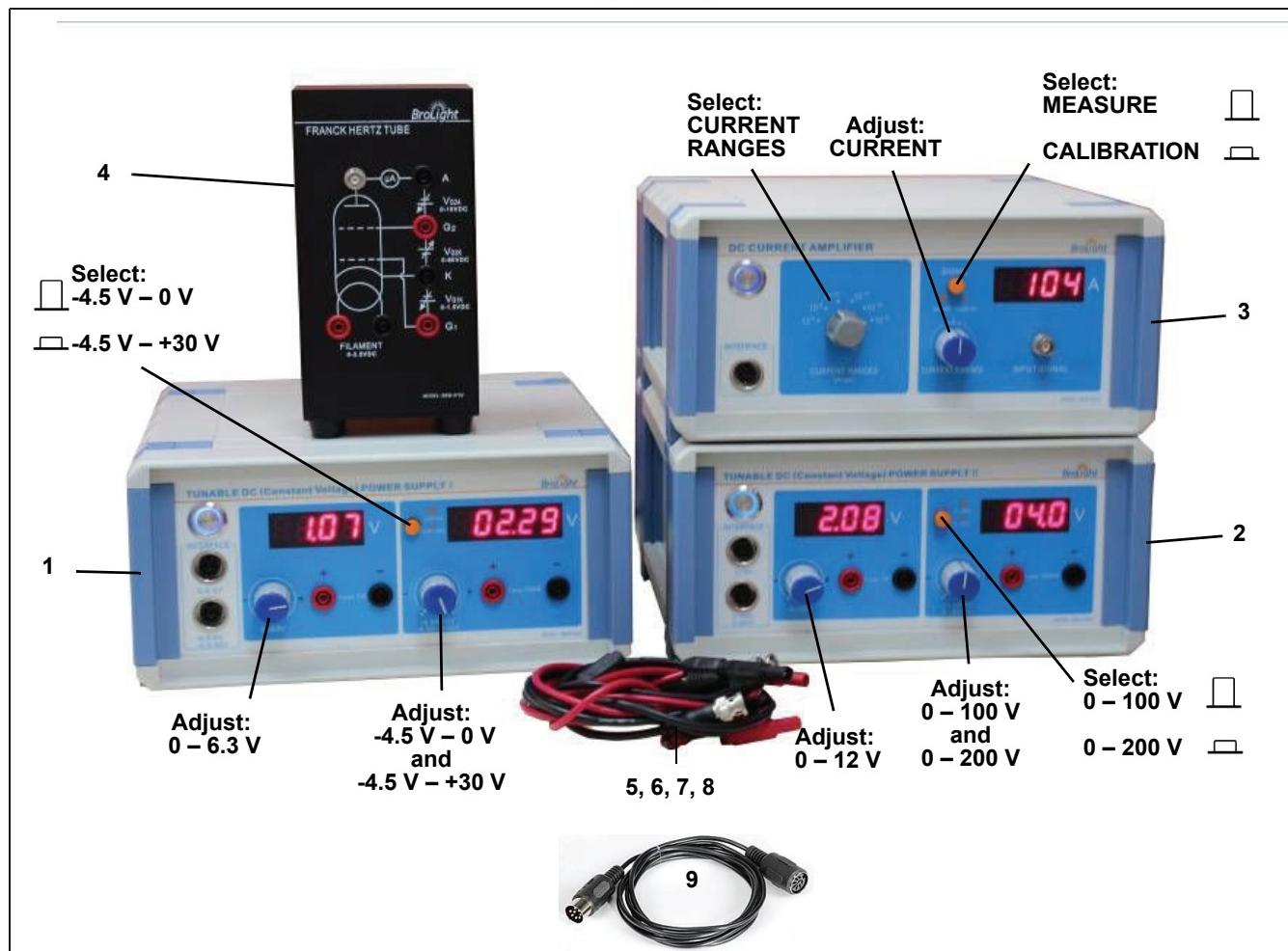
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# Franck-Hertz Experiment

SE-9639



## Equipment List

Included Equipment	Model	Quantity
1. Tunable DC (Constant Voltage) Power Supply I	SE-6615	1
2. Tunable DC (Constant Voltage) Power Supply II	SE-9644	1
3. DC Current Amplifier	SE-6621	1
4. Argon Tube Enclosure with Argon Tube	SE-9650	1
5. Connecting cable, 850 mm, red	EM-9740	Set of 5
6. Connecting cable, 850 mm, black	EM-9745	Set of 5
7. Power Cord	-	3
8. BNC Cable	-	1
9. 8-pin DIN Extension Cable	UI-5218	2

## Recommended Items

Item	Model	Quantity
850 Universal Interface	UI-5000	1
PASCO Capstone Software	UI-5400	1

## Limited Warranty and Limitation of Liability

This BroLight product is free from defects in material and workmanship for one year from the date of purchase. This warranty does not cover fuses, or damage from accident, neglect, misuse, alteration, contamination, or abnormal conditions of operation or handling. Resellers are not authorized to extend any other warranty on BroLight's behalf. To obtain service during the warranty period, return the unit to point of purchase with a description of the problem. THIS WARRANTY IS YOUR ONLY REMEDY. NO OTHER WARRANTIES, SUCH AS FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSED OR IMPLIED. BROLIGHT IS NOT LIABLE FOR ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES OR LOSSES, ARISING FROM ANY CAUSE OR THEORY. Since some states or countries do not allow the exclusion or limitation of an implied warranty or of incidental or consequential damages, this limitation of liability may not apply to you.

## Safety Information



**WARNING:** To avoid possible electric shock or personal injury, follow these guidelines.

- Do not clean the equipment with a wet cloth.
- Before use, verify that the apparatus is not damaged.
- Do not defeat power cord safety ground feature.
- Plug into a grounded (earthed) outlet.
- Do not use the product in any manner that is not specified by the manufacturer.
- Do not install substitute parts or perform any unauthorized modification to the product.
- Line and Current Protection Fuses: For continued protection against fire, replace the line fuse and the current-protection fuse only with fuses of the specified type and rating.
- Main Power and Test Input Disconnect: Unplug instrument from wall outlet, remove power cord, and remove all probes from all terminals before servicing. Only qualified, service-trained personnel should remove the cover from the instrument.
- Do not use the equipment if it is damaged. Before you use the equipment, inspect the case. Pay particular attention to the insulation surrounding the connectors.
- Do not use the equipment if it operates abnormally. Protection may be impaired.
- When in doubt, have the equipment serviced.
- Do not operate the equipment where explosive gas, vapor, or dust is present. Don't use it under wet conditions.
- Do not apply more than the rated voltage, as marked on the apparatus, between terminals or between any terminal and earth ground.
- When servicing the equipment, use only specified replacement parts.
- Use caution when working with voltages above 30 V AC rms, 42 V peak, or 60 V DC. Such voltages pose a shock hazard.
- To avoid electric shock, do not touch any bare conductor with hand or skin.
- Adhere to local and national safety codes. Individual protective equipment must be used to prevent shock and arc blast injury where hazardous live conductors are exposed.

- Special note: If a dangerous voltage is applied to an input terminal, then the same voltage may occur at all other terminals.

## Electrical Symbols

	Alternating Current
	Direct Current
	Caution, risk of danger, refer to the operating manual before use.
	Caution, possibility of electric shock
	Earth (ground) Terminal
	Protective Conductor Terminal
	Chassis Ground
	Conforms to European Union directives.
	WEEE, waste electric and electronic equipment
	Fuse
	On (Power)
	Off (Power)
	In position of a bi-stable push control
	Out position of a bi-stable push control

## Installation and Maintenance

### WARNING:



To reduce the risk of electric shock or damage to the instrument, turn the power switch off and disconnect the power cord before replacing a tube.

## Replace the Argon Tube

- Use a flat-blade screwdriver to remove the two small screws that hold the back plate onto the argon tube enclosure.
- Use a small flat-blade screwdriver to pry the back panel off of the enclosure.
- Pull up on the elastic pressing spring and rotate it off the argon tube.
- Gently pull out the argon tube.
- Then, install a new tube and replace the elastic pressing spring.
- Finally, close the case and replace the two small screws.

• **Note:** The tube is a thin-walled, evacuated glass bulb. Handle with care! Do not expose the tube to mechanical stress or strain.



Argon Tube Specifications	
Filling gas	argon
Filament voltage	≤ 6.3 V DC
Accelerating voltage	≤ 100 V DC
Wave crest (or trough) number	6
Life span	≥ 2000 hours

Note: Replace the argon tube with the same type: Model SE-9645 Franck-Hertz Ar-Tube.

## Fuse Replacement

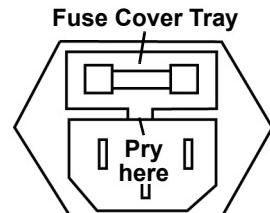
The fuse is inside a tray. Open the cover to remove the fuse.



### WARNING

To reduce the risk of electric shock or damage to the instrument, turn the power switch OFF and disconnect the power cord before replacing a fuse.

- Disconnect the power cord from the instrument.
- Open the fuse cover and remove the fuse. (The fuse is inside a tray. Use a small screwdriver or other tool to pry the tray open.)
- Replace the fuse(s). Use the same type of fuse (250 V T2A).
- Reconnect the power cord and turn on the instrument.
- If the problem persists, contact BroLight Corporation for service.



Note: Replace the burned fuses with new fuses of the same type. (One spare fuse is included.)

## Introduction

In 1914, James Franck and Gustav Hertz discovered in the course of their investigations an “energy loss in distinct steps for electrons passing through mercury vapor”, and a corresponding emission at the ultraviolet line ( $\lambda = 254$  nm) of mercury. As it is not possible to observe the light emission directly, demonstrating this phenomenon requires extensive and cumbersome experiment apparatus. They performed this experiment that has become one of the classic demonstrations of the quantization of atomic energy levels. They were awarded the Nobel Prize for this work in 1925.

In this experiment, we will repeat Franck and Hertz's energy-loss observations, using argon, and try to interpret the data in the context of modern atomic physics. We will not attempt the spectroscopic measurements, since the emissions are weak and in the extreme ultraviolet portion of the spectrum.

## Principle of the Experiment

The Franck-Hertz tube is an evacuated glass cylinder with four electrodes (a “tetrode”) which contains argon. The four electrodes are: an indirectly heated oxide-coated cathode as an electron source, two grids  $G_1$  and  $G_2$  and a plate A which serves as an electron collector (anode A). Grid 1 ( $G_1$ ) is positive with respect to the cathode (K) (about 1.5 V). A variable potential difference is applied between the cathode and Grid 2 ( $G_2$ ) so that electrons emitted from the cathode can be accelerated to a range of electron energies. The distance between the cathode and the anode is large compared with the mean free path length in the argon in order to ensure a high collision probability. On the other hand, the separation between  $G_2$  and the collector electrode (A) is small. A small constant negative potential  $U_{G2A}$  (“retarding potential”) is applied between  $G_2$  and the collector plate A (i.e. A is less positive than  $G_2$ ). The resulting electric field between  $G_2$  and collector electrode A opposes the motion of electrons to the collector electrode, so that electrons which have kinetic energy less than  $e \cdot U_{G2A}$  at Grid 2 cannot reach the collector plate A. As will be shown later, this retarding voltage helps to differentiate the electrons having inelastic collisions from those that don't.

A sensitive current amplifier is connected to the collector electrode so that the current due to the electrons reaching the collector plate may be measured. As the accelerating voltage is increased, the following is expected to happen: Up to a certain voltage, say  $V_1$ , the plate current  $I_A$  will increase as more electrons reach the plate. When the voltage  $V$  is reached, it is noted that the plate current,  $I_A$ , takes a sudden drop. This is due to the fact that the electrons just in front of the grid  $G_2$  have gained enough energy to collide inelastically with the argon atoms. Having lost energy to the argon atom, they do not have sufficient energy to overcome the retarding voltage between  $G_2$  and collector electrode A. This causes a decrease in the plate current  $I_A$ . Now as the voltage is again increased, the electrons obtain the energy necessary for inelastic collisions before they reach the anode. After the collision, by the time they reach the grid, they have obtained enough energy to overcome the retarding voltage and will reach the collector plate. Thus  $I_A$  will increase. Again when a certain voltage  $V_2$  is reached we note that  $I_A$  drops. This means that the electrons have obtained enough energy to have two inelastic collisions before reaching the grid  $G_2$ , but have not had enough remaining energy to overcome the retarding voltage. Increasing the voltage again,  $I_A$  starts upward until a third value,  $V_3$ , of the voltage is reached when  $I_A$  drops. This corresponds to the electrons having three inelastic collisions before reaching the anode, and so on. The interesting fact is that  $V_3 - V_2$  equals  $V_2 - V_1$ , etc., which shows that the argon atom has definite excitation levels and will absorb energy only in quantized amounts.



When an electron has an inelastic collision with an argon atom, the kinetic energy lost to the atom causes one of the outer orbital electrons to be pushed up to the next higher energy level. This excited electron will within a very short time fall back into the ground state level, emitting energy in the form of photons. The original bombarding electron is again accelerated toward the grid anode. Therefore, the excitation energy can be measured in two ways: by the method outlined above, or by spectral analysis of the radiation emitted by the excited atom.

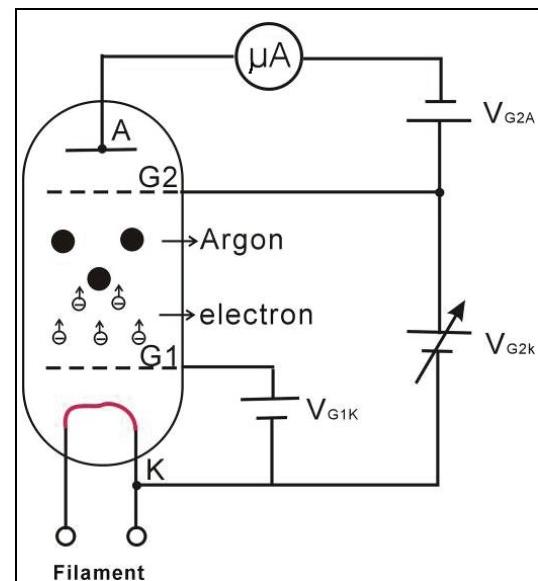


Figure 1.1: Franck-Hertz tube

Figure 2 displays a typical measurement of the anode current,  $I_A$ , as a function of the accelerating voltage. As soon as  $V_{G2K} > V_{G2A}$  the current increases with rising  $V_{G2K}$ . Notice that the current sharply decreases for a voltage  $U_1$  and then increases up to  $U_2$ , and then this pattern recurs. The interpretation of these observations is successful with the following assumptions:

- Having reached energy of about  $e \cdot U_0$ , electrons can transmit their kinetic energy to a discrete excitement state of the argon atoms.
- As a result of the inelastic collision, they pass the braking voltage.
- If their energy is twice the required value, or  $2 e \cdot U_0$ , they can collide two times inelastically and similarly for higher voltages.
- As a matter of fact, a strong line can be found for emission and absorption corresponding to an energy of  $e \cdot U_0$ , the excitation energy of argon, in the optical spectrum (108.1 nm).

In figure 2, the resonance voltage is denoted by  $U_0$ .

$$e \cdot U_0 = h f = h c / \lambda$$

or

$$h = e \lambda \left( \frac{U_0}{c} \right)$$

where **e** is the charge on an electron, **h** is Planck's Constant, and **c** is the speed of light.

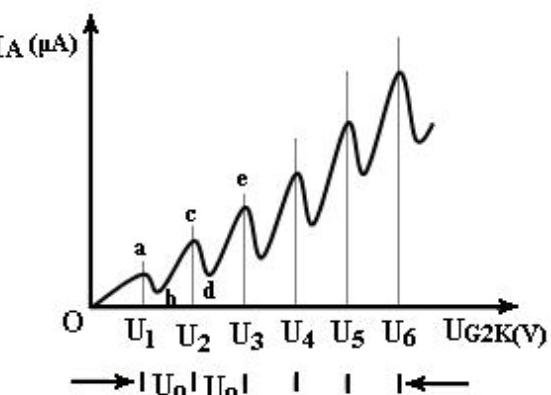


Figure 1.2: Anode current curve

## Connect Cables and Cords

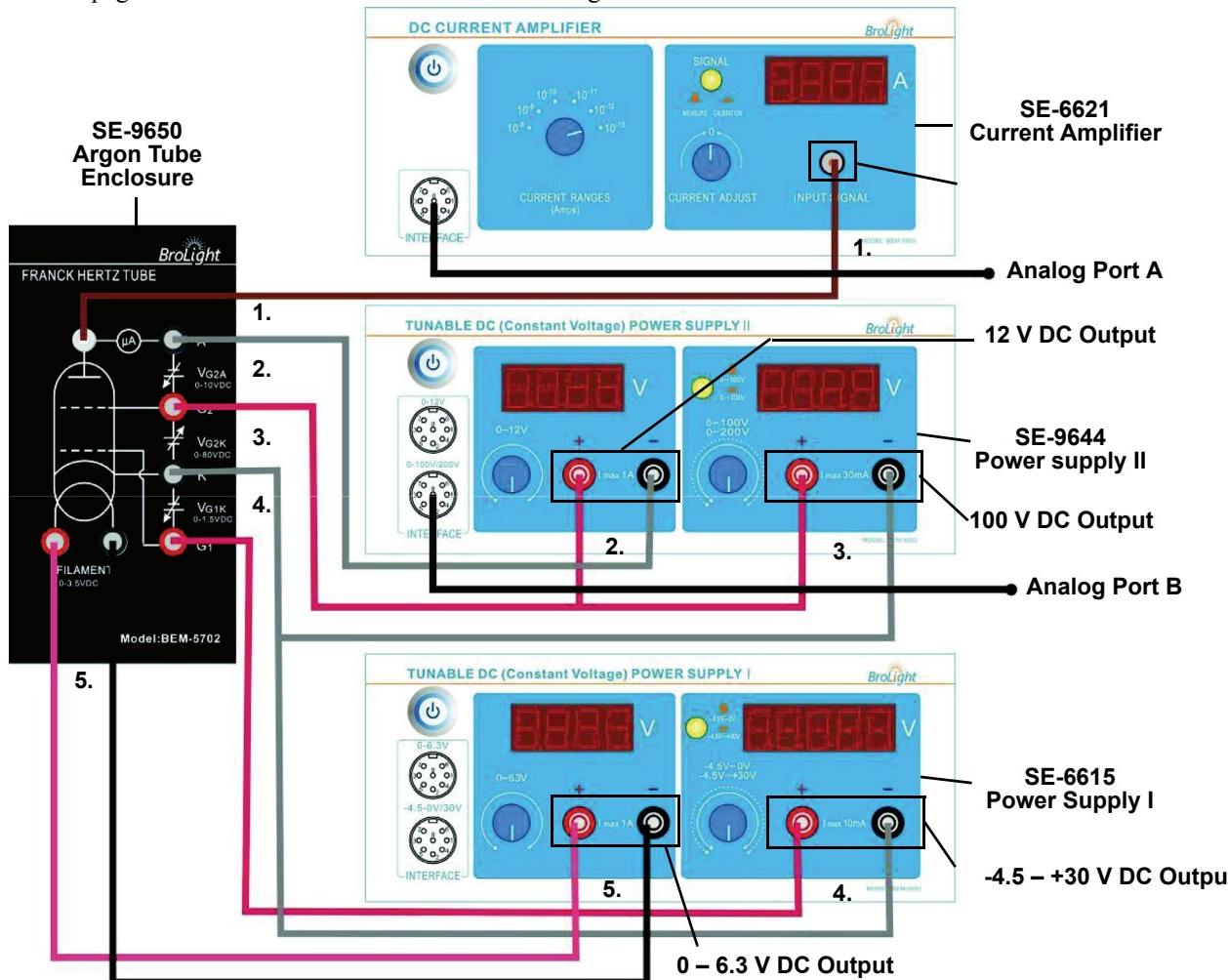
**110 - 120 V or 220 - 240 V**

Please make sure that you select the right setting according to your AC voltage level.



**Note:** Before connecting any cords or cables, be sure that all power switches on the Power Supplies and Current Amplifier are in the OFF position and all voltage controls are turned fully counterclockwise.

See the next page for numbered instructions about connecting cables and cords.



1. On the DC Current Amplifier, connect the special BNC-to-BNC cable between the port on the amplifier marked “**INPUT SIGNAL**” and the port on the Argon Tube Enclosure marked “ $\mu\text{A}$ ”.
  2. On Power Supply II, (SE-9644) connect the positive terminal of the **12 V DC** output to the grid-like electrode labeled “**G2**” (red sockets) on the Argon Tube Enclosure (SE-9650) and connect the negative terminal of the **12 V DC** output to the terminal labeled “**A**” (black sockets) on the enclosure.
  3. On Power Supply II, connect the positive terminal of the **100 V DC** output on the power supply to the grid-like electrode labeled “**G2**” (red sockets) on the Argon Tube Enclosure and connect the negative terminal of the power supply to the terminal labeled “**K**” (black sockets) on the enclosure.
  4. On Power Supply I (SE-6615), connect the positive terminal of the **-4.5 – +30 V DC** output on the power supply to the grid-like electrode labeled “**G1**” on the Argon Tube Enclosure and connect the negative terminal of the power supply to the terminal labeled “**K**” (black sockets) on the enclosure,
  5. On Power Supply I, connect the positive terminal of the **0 – 6.3 V DC** output on the power supply to the red socket of the port labeled “**FILAMENT**” on the Argon Tube enclosure and connect the negative terminal of the power supply to the black socket of the “**FILAMENT**” port.
- **Note:** Before connecting the power cords, please check that the setting for the input voltage range (110 – 120 V or 220 – 240 V) matches the local AC voltage. For the two power supplies and the current amplifier, connect a power cord between the port on the back labeled “**AC POWER CORD**” and an appropriate electrical outlet.

**DANGER:**

High Voltage is applied to the Argon Tube. Avoid contact with any part of the body.

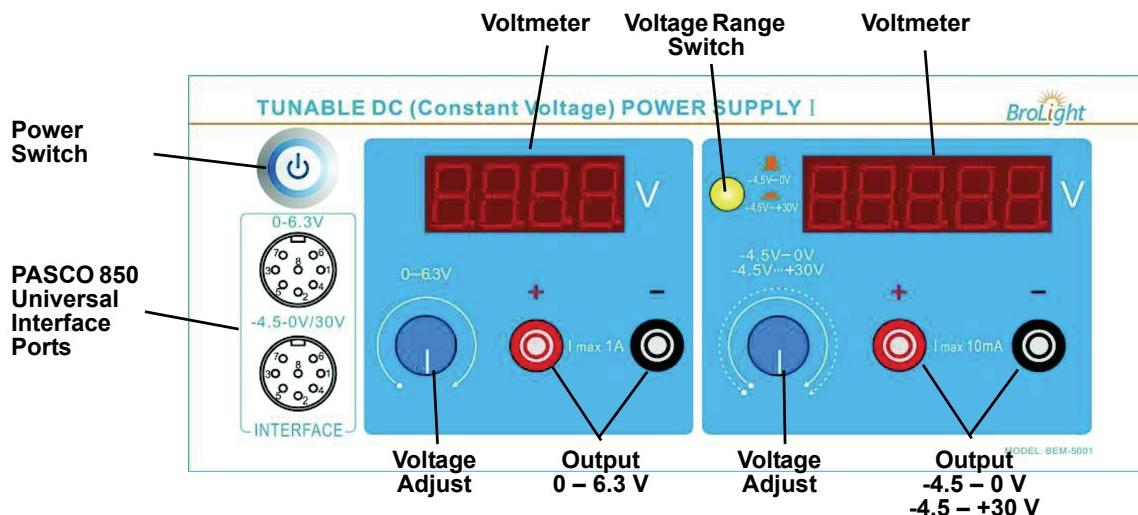
- Only use safety equipment leads (shrouded patch cords) for connections.
- Make sure that the power supplies and current amplifier are OFF before making the connections.
- Make sure that the power supplies and current amplifier are OFF before installing or replacing the argon tube in the Argon Tube Enclosure

Cables and Cords	Specification
Power Cord	Length: 1.5 m, 16 A / 250 V
Connecting Cable, Red (EM-9740)	Length: 0.85 m, 10 A / 300 V
Connecting Cable, Black (EM-9745)	Length: 0.85 m, 10 A / 300 V
BNC-to-BNC Cable	Length: 1.0 m, 1 A / 300 V

Note: Replace the cables and power cords with the same type.

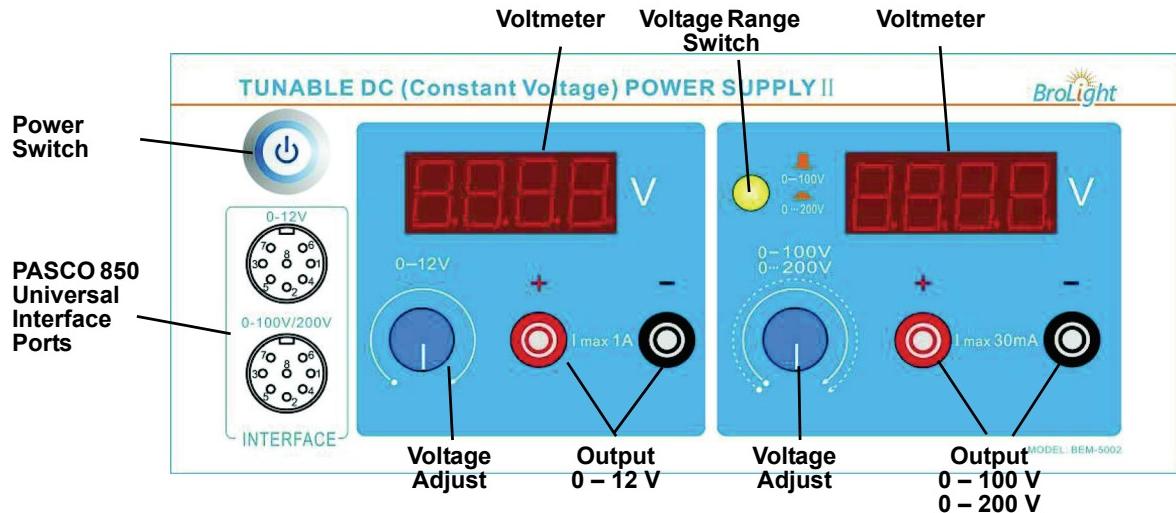
# Franck-Hertz Experiment Tunable DC (Constant Voltage) Power Supply I

## Tunable DC (Constant Voltage) Power Supply I



- Voltmeter: Displays voltage across the argon tube.
- Voltage Range Switch: Sets the voltage range as -4.5 – 0 V (□) or -4.5 – +30 V (□).
- Power Switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the voltage across the argon tube.
- Output: Output power.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.

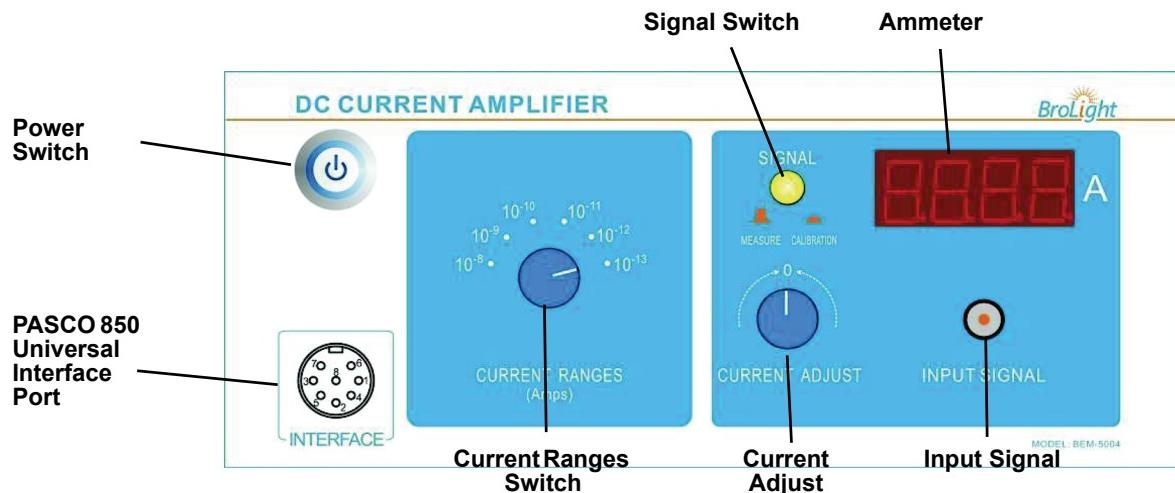
## Tunable DC (Constant Voltage) Power Supply II



- Voltmeter: Displays voltage across the argon tube.
- Voltage Range Switch: Sets the voltage range as 0 to 100 V (□) or 0 to 200 V (□) for the accelerating voltage.
- Power Switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the voltage for both voltage ranges.

- Output: Output power.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.

### DC Current Amplifier



- Power Switch: Turns the power to the instrument ON or OFF.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.
- Current Range Switch: Sets the current range for the instrument's current amplifier ( $10^{-8}$  to  $10^{-13}$  A).
- Signal Switch: Sets the signal to MEASURE (█) or CALIBRATION (□).
- Current Adjust: Sets the current through the instrument to zero.
- Ammeter: Displays the current through the argon tube.
- Input Signal: Input current signal.

# Experiment Procedure 1

## Adjust Operating Voltages

**Note:** Before switching on the power, be sure that all voltage controls are turned fully counterclockwise.

1. Connect all the cables and cords as shown in the section “Connect Cables and Cords” (page 7).
2. On the Tunable DC (Constant Voltage) Power Supply I, Tunable DC (Constant Voltage) Power Supply II, and the DC Current Amplifier, push in the Power Switch to the ON position.
3. On the DC Current Amplifier, turn the CURRENT RANGES switch to  $10^{-10}$  A. To set the current amplifier to zero, press the SIGNAL button in to CALIBRATION. Adjust the CURRENT CALIBRATION knob until the current reads zero. Press the SIGNAL button to MEASURE.
4. On the DC (Constant Voltage) Power Supply I, set the Voltage Range switch to -4.5 – +30 V. On Power Supply II, set the Voltage Range switch to 0 – 100 V.
5. On Power Supply I, rotate the 0 – 6.3 V adjust knob until the voltmeter reads 3.5 V. This sets  $V_H = 3.5$  V (Filament Voltage). Note: The Argon Tube Enclosure may have a different suggested filament voltage. If so, use it instead of 3.5 V.
6. On Power Supply I, rotate the -4.5 – +30 V adjust knob until the voltmeter reads 1.5 V. This sets  $V_{G1K} = 1.5$  V (the voltage between the first grid and the cathode)
7. Rotate the 0 – 12 V adjust knob until the voltmeter reads 10.0 V to set  $V_{G2A} = 10.0$  V (Retarding voltage).
8. Rotate the 0 – 100 V adjust knob until the voltmeter reads 0 V. This sets  $V_{G2K} = 0$  V (Accelerating voltage).
9. Remember, allow the argon tube and the apparatus to warm up for 15 minutes.
10. When you have finished the above steps, check that  $V_H = 3.5$  V (Filament voltage),  $V_{G1K} = 1.5$  V (the voltage between the first grid and cathode), and  $V_{G2A} = 10.0$  V (voltage between the second grid and anode – “retarding voltage”). If so, the equipment is ready to do the experiment. Note: These are suggested settings for the experiment, but other values could be tried. You can do the experiment by parameters that are marked on the Argon Tube Enclosure.



*NOTE: It is very important to allow the argon tube and apparatus to warm up for 15 minutes prior to making any measurements.*

## Manual Measurements

Note:

- During the experiment, pay attention to the output current ammeter when the voltage is over 60 V. If the ammeter's reading increases suddenly, decrease the voltage at once to avoid the damage to the tube.
- If you want to change the value of  $V_{G1K}$ ,  $V_{G2A}$  and  $V_H$  during the experiment, rotate the "0 ~ 100 V" adjust knob fully counter-clockwise before making the changes.
- The filament voltage is tunable from 0 to 6.3V. If the anode output current is too high and causes the amplifier to overflow, the filament voltage should be decreased.
- As soon as you have finished the experiment, return the  $V_{G2A}$  voltage to 0 V to prolong the life of the argon tube.

- Increase the accelerating voltage  $V_{G2K}$  by a small amount (for example, 1 V). Record the new accelerating voltage  $V_{G2K}$  (value read on voltmeter) and current  $I_A$  (read on "Ammeter") in Table 1:1. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 1:1. Stop when the accelerating voltage  $V_{G2K} = 85V$ . (If the current  $I_A$  exceeds the range, reduce the filament voltage (for example, 0.1V) and start over again.)
- Try to identify the "peak positions", i.e. watch for those values of the accelerating voltage  $V_{G2K}$  for which the current reaches a local maximum and begins to drop on further increase of the accelerating voltage. Take a few data points ( $V_{G2K}$ ,  $I_A$ ) around these peak positions and record them in Table 1:2. Try to identify the "valley positions", i.e. watch for those values of the accelerating voltage  $V_{G2K}$  for which the current reaches a local minimum and begins to rise on further increase of the accelerating voltage. Take a few data points ( $V_{G2K}$ ,  $I_A$ ) around these valley positions and record them in Table 1:2.
- Take sufficiently many voltage values so as to allow you to determine the positions of the peaks and valleys.

**Table 1.1: Accelerating Voltage and Tube Current**

$V_{G2K}$ (V)									
$I_A$ ( $\times 10^{-10}$ A)									

**Table 1.2: Peak and Valley Voltages**

		$V_1$	$V_2$	$V_3$	$V_4$	$V_5$	$V_6$
<b>Peak positions</b>	$V_{G2K}$ (V)						
	$I_A$ ( $\times 10^{-10}$ A)						
<b>Valley positions</b>	$V_{G2K}$ (V)						
	$I_A$ ( $\times 10^{-10}$ A)						

## Analysis

- Plot the graphs of Current (y-axis) versus Voltage (x-axis).

2. Find the peak (or valley) positions which match the accelerating voltages labeled “V1, V2, V3, V4, V5, and V6”.
3. Obtain the value of argon atom’s first excitation potential ( $V_0$ ).

$$V_0 = \frac{(V_2 - V_1) + (V_3 - V_2) + (V_4 - V_3) + (V_5 - V_4) + (V_6 - V_5)}{5}$$

4. Calculate the value of Planck’s Constant,  $\mathbf{h}$ :

$$\mathbf{h} = e\lambda\left(\frac{V_0}{c}\right)$$

where  $e = 1.602 \times 10^{-19} \text{ C}$ ,  $\lambda = 108.1 \text{ nm}$ , and  $c = 3 \times 10^8 \text{ m/s}$ .

5. Calculate the percent difference between the experimental value and the accepted value ( $h_0 = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ )

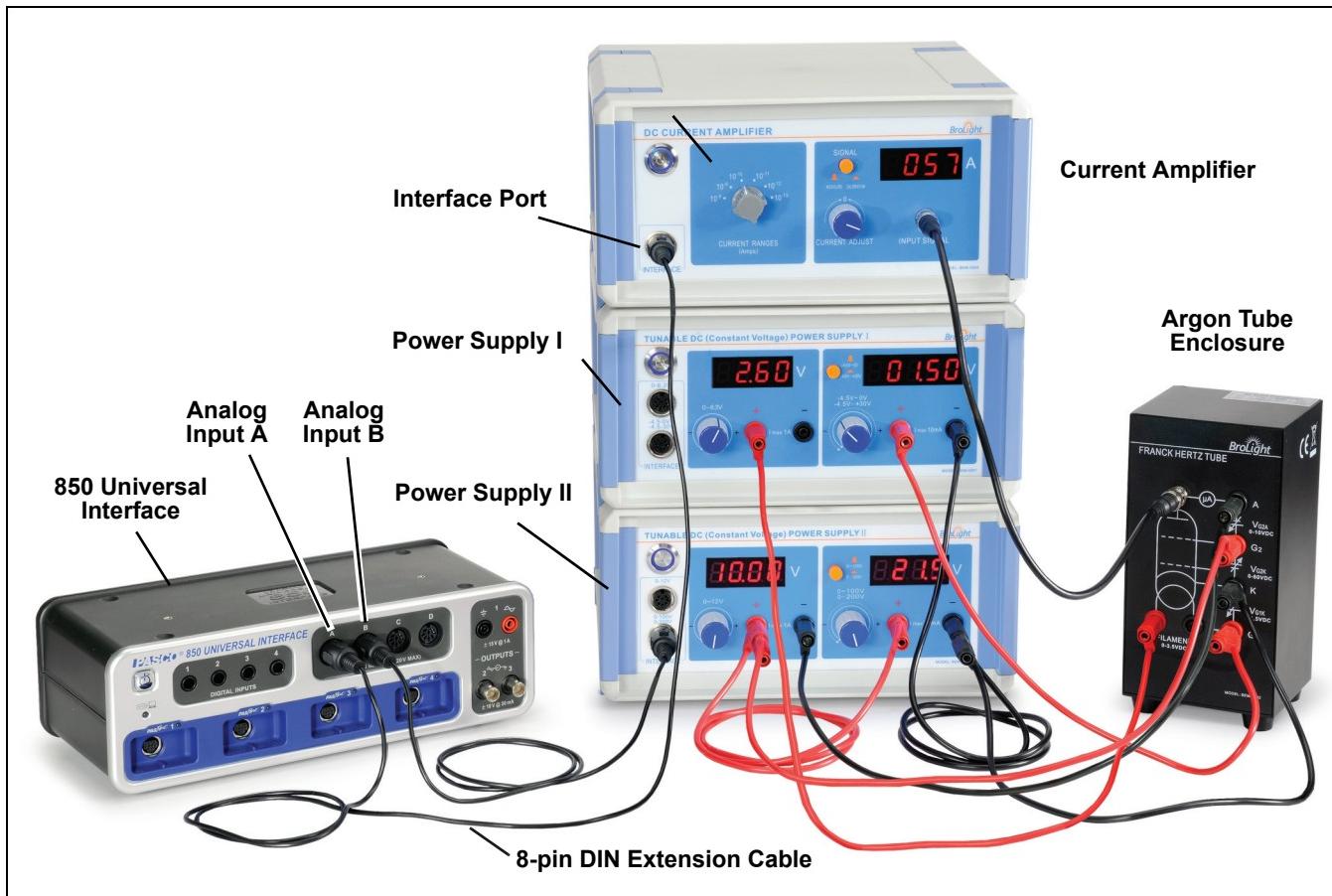
$$\Delta h = |(h - h_0) / h_0| \times 100\% =$$

## Questions

1. Should you use the positions of the peaks or of the valleys to determine the excitation energy? Or both? Explain.
2. Why are the peaks and valleys smeared out rather than sharp?
3. How precisely can you determine the peak/valley position? Explain and justify your estimates.
4. How would molecular contaminants in the tube affect your results?

## Experiment Procedure 2

### Using a PASCO Interface and Data Acquisition Software



### Items Needed

Item*	Quantity
850 Universal Interface (UI-5000)	1
PASCO Capstone Software (UI-5400)	1

\*See the PASCO web site at [www.pasco.com](http://www.pasco.com) for more information

### Hardware Setup: Connect Cables and Cords

**Note:** Before connecting any cords or cables, be sure that all power switches on the Interface, Power Supplies, and Current Amplifier are in the OFF position and all voltage controls are turned fully counterclockwise.

1. Connect all the cables and cords between the argon tube enclosure and the power supplies and current amplifier.
2. Connect one 8-pin DIN Extension Cable (UI-5218) from the INTERFACE port on the DC Current Amplifier to ANALOG INPUT A on the Universal Interface (UI-5100).

3. Connect a second 8-pin DIN Extension Cable from the 0 - 100V / 0 - 200V INTERFACE port on Power Supply II to ANALOG INPUT B on the Universal Interface.
4. Turn ON the power for the Universal Interface, the power supplies, and the current amplifier.
5. On the DC Current Amplifier, turn the CURRENT RANGES switch to  $10^{-10}$  A. To set the current amplifier to zero, press the SIGNAL button in to CALIBRATION. Adjust the CURRENT CALIBRATION knob until the current reads zero. Press the SIGNAL button to MEASURE.
6. On the DC (Constant Voltage) Power Supply I, set the Voltage Range switch to -4.5 – +30 V (□). On Power Supply II, set the Voltage Range switch to 0 – 100 V (□).
7. On Power Supply I, rotate the 0 – 6.3 V adjust knob until the voltmeter reads 3.5 V. This sets  $V_H = 3.5$  V (Filament Voltage). Note: The Argon Tube Enclosure may have a different suggested filament voltage. If so, use it instead of 3.5 V.
8. On Power Supply I, rotate the -4.5 – +30 V adjust knob until the voltmeter reads 1.5 V. This sets  $V_{G1K} = 1.5$  V (the voltage between the first grid and the cathode)
9. Rotate the 0 – 12 V adjust knob until the voltmeter reads 10.0 V to set  $V_{G2A} = 10.0$  V (Retarding voltage).
10. Rotate the 0 – 100 V adjust knob until the voltmeter reads 0 V. This sets  $V_{G2K} = 0$  V (Accelerating voltage).
11. Remember, allow the argon tube and the apparatus to warm up for 15 minutes.
12. When you have finished the above steps, check that  $V_H = 3.5$  V (Filament voltage),  $V_{G1K} = 1.5$  V (the voltage between the first grid and cathode), and  $V_{G2A} = 10.0$  V (voltage between the second grid and anode – “retarding voltage”). If so, the equipment is ready for the experiment. Note: These are suggested settings for the experiment, but other values could be tried. You can do the experiment by parameters that are marked on the Argon Tube Enclosure.



*NOTE: It is very important to allow the argon tube and apparatus to warm up for 15 minutes prior to making any measurements.*

## Software Setup

1. Start the PASCO Capstone software.
2. The current is a very small number, so to make the current to appear as a number between zero and 100 on the graph, create a calculation:
  - Electron Current = [Current, Ch A (A)] × 10<sup>10</sup> with units of (x 10<sup>-10</sup> A)
3. Create a graph of “Electron Current” vs. Voltage.
4. Create a digits display of the Voltage. This will clearly show you the accelerating voltage so you can monitor it to make sure that you do not exceed 85 V.
5. Create a table and create Run-tracked User-Entered Data called **Peak Voltage** with units of (V).
6. In the second column of the table, create a calculation:
  - Diff between Peaks = diff(1,[Peak Voltage (V)]) with units of (V)  
(This calculation calculates the voltage difference between adjacent current peaks.)
7. Add a column and create Run-tracked User-Entered Data called **Trough Voltage** with units of (V).
8. In the fourth column of the table, create a calculation:

- Diff between Peaks =  $\text{diff}(1, [\text{Trough Voltage (V)}])$  with units of (V)  
(This calculation calculates the voltage difference between adjacent current troughs.)
- In the table, turn on the mean and standard deviation.

## Recording Data

- Make sure the accelerating voltage  $V_{G2K}$  is zero.
- After the filament has warmed up for about 15 minutes, click **Record** and slowly increase the accelerating voltage (take about two minutes). Do not exceed 85 V.

**CAUTION: While you are increasing the voltage, if you see the current suddenly increase, immediately return the voltage to zero and decrease the filament voltage slightly. Wait for a few minutes for it to cool, and repeat the recording.**

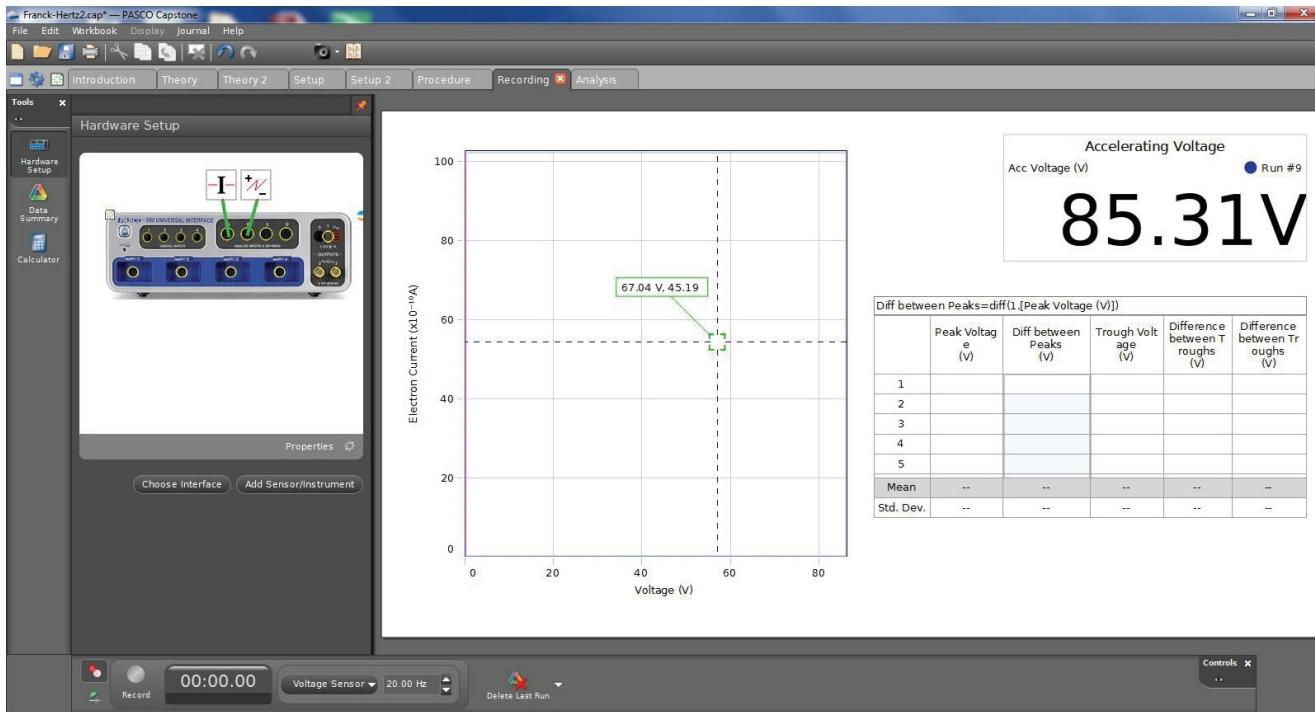
## Analysis

- Using the coordinates tool on the graph, find the voltage of each of the peaks and troughs and record them in the table in the **Peak Voltage** and Trough Voltage columns respectively.
- The voltage differences between adjacent peaks and the voltage differences between adjacent troughs will be calculated automatically in the table. Record the **mean** and **standard deviations** for the differences. The standard deviations give the uncertainties in the difference measurements.
- Use the mean voltage difference ( $V_0$ ) to calculate the value of Planck's Constant,  $h$ :

$$h = e\lambda \left( \frac{V_0}{c} \right)$$

where  $e = 1.602 \times 10^{-19}$  C,  $\lambda = 108.1$  nm and  $c = 3 \times 10^8$  m/s. The answer will be in J•s.

- Calculate the percent difference between the experimental value and the accepted value ( $h_o = 6.626 \times 10^{-34}$  J•s).
- Estimate the uncertainty in the experimental value of Planck's Constant using the uncertainty in the voltage difference.



## Appendix A: General Specifications

Item	Description
<b>Supply voltage:</b>	110 – 120 V or 220 – 240 V
<b>Supply voltage fluctuations:</b>	±10%
<b>Fuse protection for inputs:</b>	250 V T2A
<b>Display:</b>	3-1/2 or 4-1/2 digit display
<b>Using site:</b>	Indoor use
<b>Temperature:</b>	Operating: 0°C to 40°C, Storage: -20°C to 50°C
<b>Relative humidity:</b>	Noncondensing < 10°C, 90% from 10°C to 30°C, 75% from 30°C to 40°C
<b>Pollution degree:</b>	2
<b>Certifications</b>	CE
<b>Safety compliance:</b>	IEC/EN 61010-1
<b>Overshoot category:</b>	II
<b>Degree of protections:</b>	IP20
<b>Normal energy protection:</b>	5 J

Item	Description
<b>Tunable DC (Constant Voltage) Power Supply I</b>	0~6.3 V DC, $I \leq 1A$ (ripple < 1%), 3.5 Digit Display; -4.5~0 V DC / -4.5~30 V DC (ripple < 1%) (Two ranges), $I \leq 10mA$ , 4.5 Digit Display;
<b>Tunable DC (Constant Voltage) Power Supply II</b>	0~12 V DC, $I \leq 1A$ (ripple < 1%), 3.5 Digit Display; 0~100 V DC / 0~200 V DC (ripple < 1%) (Two ranges), $I \leq 30mA$ , 3.5 Digit Display
<b>DC Current Amplifier</b>	Current range: $10^{-8} \sim 10^{-13}$ A, in six ranges, 3.5 Digit Display; Zero drift $\leq \pm 1\%$ of full range reading in 30 minutes at the range of $10^{-13}$ A (after a 20 minute warm-up)
<b>Argon Tube</b>	Filling gas: argon Filament voltage: $\leq 6.3$ V DC Accelerating voltage: $\leq 100$ V DC Wave crest (or trough) number: 6 Life span: $\geq 2000$ hours

## Appendix B: Teacher's Notes

### Sample Data 1: Manual Measurements

Filament voltage (V) = 3.55 V

$V_{G1K}$  = 1.5 V

$V_{G2A}$  = 11.0 V

**Table 1: Accelerating Voltage and Tube Current**

$V_{G2K}$ (V)	1	2	3	4	5	6	7	8	9	10
$I_A$ ( $\times 10^{-10}$ A)	0	0	0	0	0	0	0	0	0	0
$V_{G2K}$ (V)	11	12	13	14	15	16	17	18	19	20
$I_A$ ( $\times 10^{-10}$ A)	0	0	1	5	14	32	59	81	112	128
$V_{G2K}$ (V)	21	22	23	24	25	26	274	28	29	30
$I_A$ ( $\times 10^{-10}$ A)	143	153	153	145	130	118	131	183	270	343
$V_{G2K}$ (V)	31	32	33	34	35	36	37	38	39	40
$I_A$ ( $\times 10^{-10}$ A)	413	448	441	391	332	243	173	145	220	417
$V_{G2K}$ (V)	41	42	43	44	45	46	47	48	49	50
$I_A$ ( $\times 10^{-10}$ A)	609	772	825	806	702	547	352	199	113	197
$V_{G2K}$ (V)	51	52	53	54	55	56	57	58	59	60
$I_A$ ( $\times 10^{-10}$ A)	446	771	1032	1174	1216	1101	883	660	343	167
$V_{G2K}$ (V)	61	62	63	64	65	66	67	68	69	70
$I_A$ ( $\times 10^{-10}$ A)	118	323	671	1093	1351	1522	1514	1369	1104	756
$V_{G2K}$ (V)	71	72	73	74	75	76	77	78	79	80
$I_A$ ( $\times 10^{-10}$ A)	468	260	227	456	842	1270	1561	1730	1760	1621
$V_{G2K}$ (V)	81	82	83	84	85					
$I_A$ ( $\times 10^{-10}$ A)	1395	1055	727	460	443					

Franck-Hertz Curve for Argon

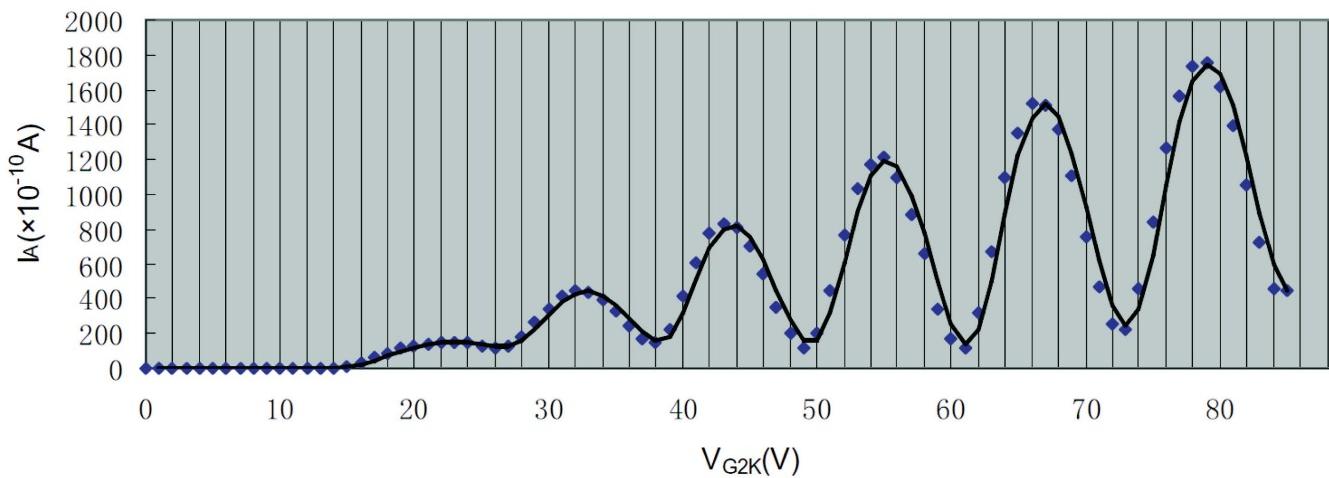


Table 2: Peak and Valley Voltages

		V <sub>1</sub>	V <sub>2</sub>	V <sub>3</sub>	V <sub>4</sub>	V <sub>5</sub>	V <sub>6</sub>
<b>Peak positions</b>	V <sub>G2K</sub> (V)	22.5	32	43	55	66	79
	I <sub>A</sub> (x 10 <sub>-10</sub> A)	153	448	825	1216	1522	1760
<b>Valley positions</b>	V <sub>G2K</sub> (V)	13	26	38	49	61	73
	I <sub>A</sub> (x 10 <sub>-10</sub> A)	1	118	145	113	118	227

## Analysis

Obtain the value of argon atom's first excitation potential ( $V_0$ ):

$$V_0(\text{peak}) = (V_6 - V_1)/5 = 11.3 \text{ V};$$

$$V_0(\text{valley}) = (V_6 - V_1)/5 = 12.0 \text{ V};$$

$$\text{Therefore: } V_0 = 11.65 \text{ V};$$

Calculate the value of Planck's Constant,  $h$

$$h = e\lambda \left( \frac{V_0}{c} \right)$$

where  $e = 1.602 \times 10^{-19} \text{ C}$ ,  $\lambda = 108.1 \text{ nm}$ , and  $c = 3 \times 10^8 \text{ m/s}$ . Based on the data, Planck's Constant,  $h = 6.725 \times 10^{-34} \text{ J}\cdot\text{s}$

Calculate the percent difference between the experimental value and the accepted value ( $h_0 = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ )

$$\Delta h = |(h - h_0) / h_0| \times 100\% = 1.5\%.$$

## Questions

1. Should you use the positions of the peaks or of the valleys to determine the excitation energy? Or both? Explain.

Use both. The average of the accelerating voltages matching peak positions and the valley positions is the voltage for the approximate excitation energy,  $e \cdot U_0$ .

- Why are the peaks and valleys smeared out rather than sharp?

The shape of the peaks and valleys in the curve is affected by the fact that there is a potential drop of 1.5 V at the cathode, which is the source of the electrons. The cathode potential causes the peaks and valleys to occur over a space of 1.5 V, rather than at a sharp point.

- How precisely can you determine the peak/valley position? Explain and justify your estimates.

Note that the current fluctuations in the vicinity of the peaks, the width of the peaks, the steepness of the drop-off or rise, and background height and shape all may play a role in this

- How would molecular contaminants in the tube affect your results?

The molecular contaminant in the tube has a different first excitation potential ( $V_0$ ), so that the measurement of argon atom's first excitation potential would be affected.

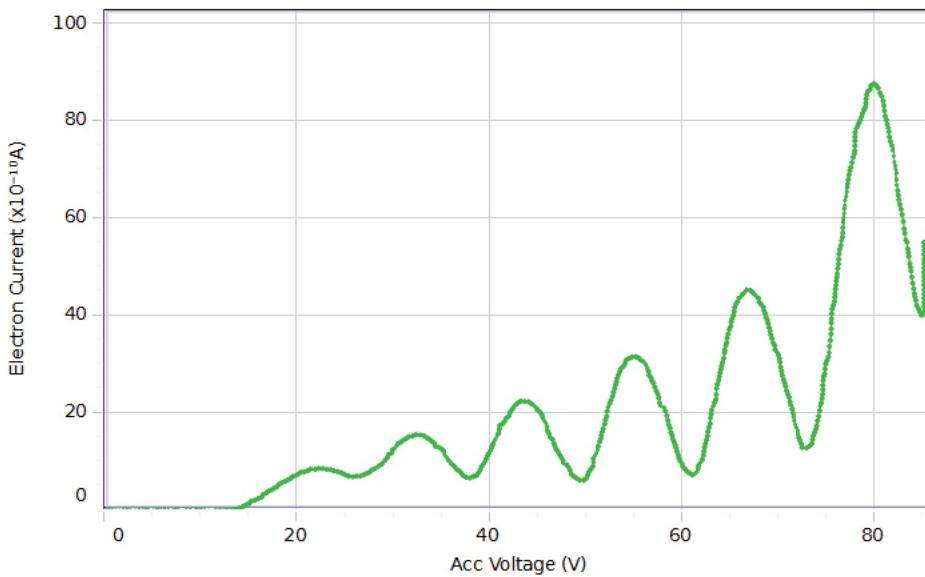
### Sample Data 2: Using a PASCO Interface

Filament voltage (V) = 3.55 V

$V_{G1K}$  = 1.5 V

$V_{G2A}$  = 11.0 V

	Run #9
All $\Delta V$ (V)	
2	11.08
3	11.34
4	11.88
5	11.44
6	12.09
7	11.13
8	11.94
Mean	11.44
Std. Dev.	0.50



Diff between Peaks=diff(1,[Peak Voltage (V)])				
	Peak Voltage (V)	Diff between Peaks (V)	Trough Voltage (V)	Difference between Troughs (V)
1	22.11	10.62	26.51	11.44
2	32.73	11.08	37.95	12.09
3	43.81	11.34	50.04	11.13
4	55.15	11.88	61.17	11.94
5	67.03		73.11	
Mean	44.17	11.23	49.76	11.65
Std. Dev.	17.75	0.53	18.41	0.44

## Analysis

Obtain the value of argon atom's first excitation potential:  $V_0 = 11.44 \text{ V}$ ;

Calculate the value of Planck's Constant,  $h$

$$h = e\lambda \left( \frac{V_0}{c} \right)$$

where  $e = 1.602 \times 10^{-19} \text{ C}$ ,  $\lambda = 108.1 \text{ nm}$ , and  $c = 3 \times 10^8 \text{ m/s}$ .

Based on the data, Planck's Constant,  $h = 6.604 \times 10^{-34} \text{ J}\cdot\text{s}$

Calculate the percent difference between the experimental value and the accepted value ( $h_0 = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ )

$$\Delta h = |(h - h_0) / h_0| \times 100\% = 0.3\%.$$

Using  $V_0 = 11.44 + 0.50 \text{ V} = 11.94 \text{ V}$  gives  $h = 6.892 \times 10^{-34} \text{ J}\cdot\text{s}$ , which is  $6.892 - 6.604 = 0.29 \times 10^{-34} \text{ J}\cdot\text{s}$ . Therefore, the experimental value for  $h$  is  $(6.6 \pm 0.3) \times 10^{-34} \text{ J}\cdot\text{s}$ . So the answer is accurate to 0% to as many significant figures as we have, but the precision is only  $\pm 4.5\%$ .

## Questions

1. Should you use the positions of the peaks or of the valleys to determine the excitation energy? Or both? Explain.

Use both. The average of the accelerating voltages matching peak positions and the valley positions is the voltage for the approximate excitation energy,  $e \cdot U_0$ .

2. Why are the peaks and valleys smeared out rather than sharp?

The shape of the peaks and valleys in the curve is affected by the fact that there is a potential drop of 1.5 V at the cathode, which is the source of the electrons. The cathode potential causes the peaks and valleys to occur over a space of 1.5 V, rather than at a sharp point.

3. How precisely can you determine the peak/valley position? Explain and justify your estimates.

Note that the current fluctuations in the vicinity of the peaks, the width of the peaks, the steepness of the drop-off or rise, and background height and shape all may play a role in this

4. How would molecular contaminants in the tube affect your results?

The molecular contaminant in the tube has a different first excitation potential ( $V_0$ ), so that the measurement of argon atom's first excitation potential would be affected.

## Appendix C: Technical Support

For assistance with the equipment or any other PASCO products, contact PASCO as follows:

- Address: PASCO scientific  
10101 Foothills Blvd.  
Roseville, CA 95747-7100
- Phone: +1 916 4626 8384 (worldwide)  
877-373-0300 (U.S.)
- Web: [www.pasco.com](http://www.pasco.com)
- Email: [support@pasco.com](mailto:support@pasco.com)

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**Warranty**

For a description of the product warranty, see the PASCO catalog.

## Appendix D: Product End of Life

### Product End of Life Disposal Instructions:

This electronic product is subject to disposal and recycling regulations that vary by country and region. It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment. To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle/disposal service, or the place where you purchased the product.



The European Union WEEE (Waste Electronic and Electrical Equipment) symbol (above) and on the product or on its packaging indicates that this product must not be disposed of in a standard waste container.